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IMPLEMENTATION OF A VACUUM EFFECTOR FOR THE ABB IRB 140 INDUSTRIAL ROBOT

REALIZACE EFEKTORU S PŘÍSAVKAMI PRO PR ABB IRB 140

Abstrakt

The article describes the implementation of the vacuum effector [1]. Based on requirements such as a 1kg load capacity, a maximum acceleration of 10 m/s^2 and a source of energy – an air of 5bar pressure, it addresses a effector´s body design, presents a calculation of suction cups and also a test of the implemented vacuum effector including its evaluation.

Abstrakt

Článek se zabývá popisem realizace podtlakového efektoru. Na základě požadavků jako jsou únosnost 1 kg, maximální zrychlení 10 m/s^2, zdroj energie – vzduch o tlaku 5 bar, řeší návrh těla efektoru, předkládá výpočet přísavek i test realizovaného efektoru včetně jeho vyhodnocení.

1 INTRODUCTION

The vacuum devices are currently used in a wide range of technological applications in many industries and in a research. An executive subsystem of these devices in industrial and service robots is the effector [2]. The most common grip elements of these vacuum effectors are suction cups (passive or active). The active suction cups use for inducing a vacuum suction effect its own vacuum source – generally ejectors. The ejector is a simple device which uses the compressed air passing through the nozzle by which the negative pressure is created at the narrowest point and this area is joined with the room under the suction cup. The effectors are further specified according to given requirements of a particular application.

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2 EFFECTOR DESIGN

To the requirements laid upon the effector belong the 1 kg load capacity, the maximum acceleration of 10 m/s^2, use of the pressurized air of 5 bar as the source of energy and the utilization of the effector on the industrial robot ABB IRB 140.

The above requirements imply the need of the suction cup´s diameter calculation in order to achieve a firm attachment even in the least suitable position. The type of the suction cups with a bellow was chosen because of the toleration of minor deviations of the effector´s position to a surface of a manipulated object (MO). The suction cup has also support ribs, which are suitable for the manipulation with the MO as when a force acts perpendicular to an axis of the suction cup the support ribs increase a contact surface between the suction cup and the MO. The suction cup material was chosen with regard to the effector requirements and also to the price. The use of the NBR (nitril-butadien caoutchouc) as the material for the suction cups is the most appropriate. The calculation of the suitable diameter of the suction cup was conducted using the formula of the suction cups manufacturer - SMC company.

$$\phi D = \sqrt{\frac{4}{3,14} \cdot \frac{1}{p} \cdot \frac{F_g}{n} \cdot k \cdot 1000} = \sqrt{\frac{4}{3,14} \cdot \frac{1}{70} \cdot \frac{9,81}{4} \cdot 16 \cdot 1000} = 26,72\ mm, \quad (1)$$

where:

D – the suction cup diameter $[\mathrm{mm}]$,

p – the negative pressure of the vacuum $[kPa]$,

F_g – the force of the gravity $[\mathrm{N}]$,

n – a number of the suction cups $[\text{-}]$,

k – a safety coefficient (includes external forces and the acceleration) $[\text{-}]$.

From the above calculation is evident that the minimal suitable diameter of the suction cup is 26.72 mm. The bigger suction cup with the diameter of 32 mm, which is as close as possible to the calculated one, was chosen from the manufacturer´s catalogue.

The following model of the effector was designed in Pro/Engineer program, considering the requirement for lightweight effector at the high stiffness due to the higher acceleration [3].

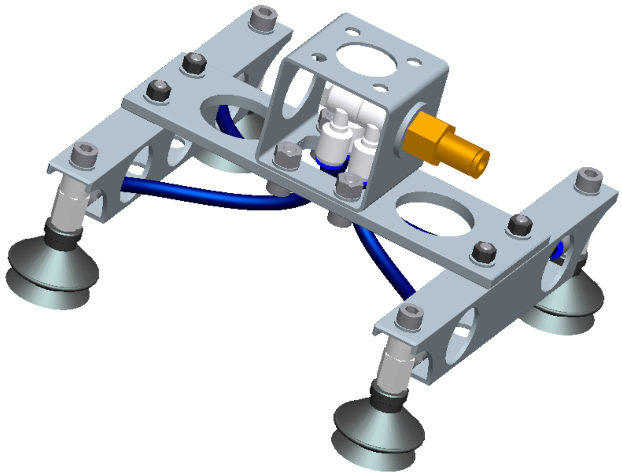

Fig. 1. The effector model.

Also the ejector ZQ1101U-K1Y5LO-D52CL-Q made by company SMC was selected as the suitable negative pressure source for the effector. This ejector was selected with regard to the compact size and the low weight by which the robot´s arm is minutely loaded. Further advantage of the ejector is its feedback, which is implemented by two adjustable values of the negative pressure. When the adjusted value is reached the ejector transmits the information about the status change from the logical 0 to 1. This function is used in the vacuum effector to control the minimum pressure required for a firm grip of the MO. In case of the manipulation with the soft or brittle materials it is appropriate to utilize this function also for the monitoring of the maximal level of vacuum at which the MO is still not damaged.

3 THE CONNECTION OF THE EJECTOR AND THE EFFECTOR

The following figures picture the ejector´s connection to the robot´s control system and the overall connection of the pneumatic circuit.

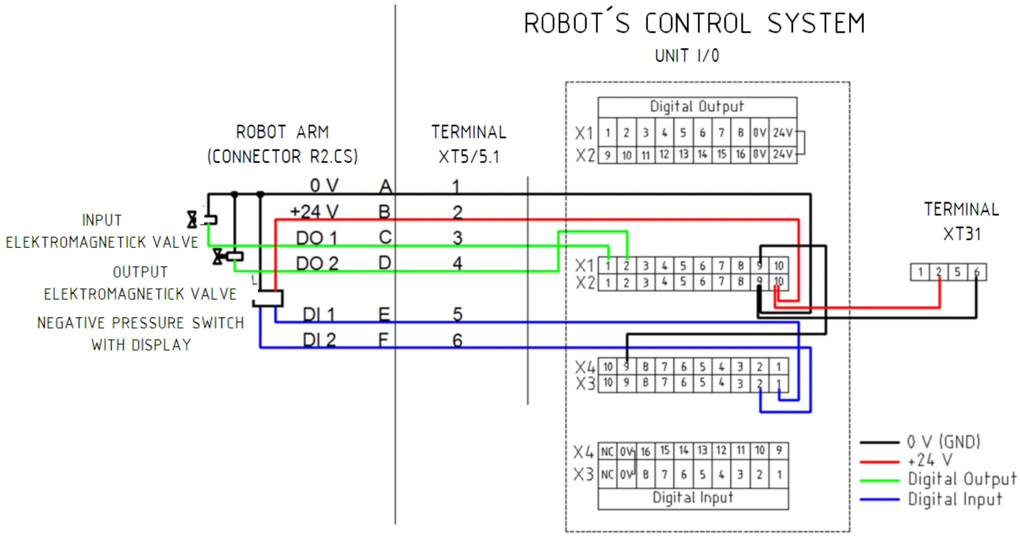

Fig. 2. The scheme of ejector´s connection to the robot´s control system ABB IRB 140.

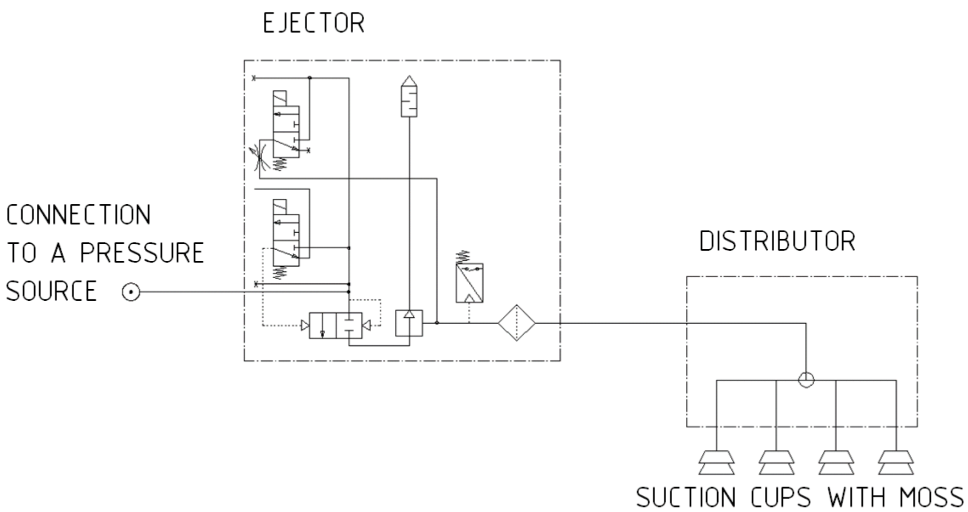

Fig. 3. The scheme of the ejector, distributor and suction cups connection.

4 EFFECTOR TEST

4.1 The calculation of the suction cups´ required force level

The main input parameters for the required force of suction cups calculation are the maximum weight of MO (1 kg), the maximum acceleration of the MO (10 m/s^2) and the number of suction cups, which is in this case four. Another important parameter is the coefficient of the friction between the suction cup and the MO. Table 1 details the friction coefficients for the possibly manipulated materials.

Tab. 1. The coefficient of the friction between the suction cup (NBR) and MO.

Material of suction cup	Material of MO	Min. coefficient	Max. coefficient	Typical coefficient
Perbunan (NBR)	plexiglass / acrylic	0.55	1.05	0.70
Perbunan (NBR)	metal			0.50
Perbunan (NBR)	cardboard	0.60	0.80	0.75
Perbunan (NBR)	hard rubber	0.75	1.25	0.80
Perbunan (NBR)	wood			0.50

Because the plexiglass board is used as the MO, it is calculated with the minimal friction coefficient for this material (0.55).

It is desirable to calculate the theoretical minimal required force of the suction cups. This force is calculated for the acceleration of MO in the vertical position and in opposite direction of gravitational acceleration, in other words in the least convenient position and direction for the manipulation with the objects. It is also required to calculate with the centrifugal force, which is maximal for the MO at minimal expansion of the arm (0.324) and at speed 1.25 m/s. This speed is 50% of the maximal TCP speed and was selected in regard to the use of the effector in the lessons, in which the maximal speed isn´t used due to the security reasons. The total minimal suction cups´ force (F) is the sum of the forces needed at maximal acceleration in the least convenient position (F1) and the centrifugal force at minimal expansion of the arm (F2).

$$F_1 = \left(\frac{m}{f}\right) \cdot (g+a) = \left(\frac{1}{0,55}\right) \cdot (9,81+10) = 36,02\ N, \tag{2}$$

where:

F_1 – the force at the maximal acceleration in the least convenient position $[\mathrm{N}]$,

m – the weight of the MO $[kg]$,

f – the friction coefficient $[\text{-}]$,

g – the gravitational acceleration $\left[\frac{m}{s^2}\right]$,

a – the effector acceleration $\left[\frac{m}{s^2}\right]$.

$$F_2 = \left(\frac{m \cdot v^2}{r+x}\right) = \left(\frac{1 \cdot 1,25^2}{0,324+0,13}\right) = 3,44\ N, \tag{3}$$

where:

F_2 – the centrifugal force at the minimal expansion of the arm $[\mathrm{N}]$,

m – the weight of MO $[kg]$,

v – the effector speed $\left[\frac{m}{s}\right]$,

r – the minimal arm expansion $[m]$,

x – the height of effector $[m]$.

$$F = F_1 + F_2 = 36,02 + 3,44 = 39,46\ N, \quad (4)$$

where:

F – the total minimal force of the suction cups $[\mathrm{N}]$,

F_1 – the force at the maximal acceleration in the least convenient position $[\mathrm{N}]$,

F_2 – the centrifugal force at the minimal expansion of the arm $[\mathrm{N}]$.

The total minimal force for the grip by the suction cups is 39.46 N.

4.2 The test description

The testing method has been conducted by the use of statistics tests in which on the MO, which was held by the effector´s suction cups, the PET bottles filled with water were gradually hanged (due to the simple determination of the load) at predetermined load. By this way the MO is gradually loaded on each levels of vacuum up to the release or up to the state in which the MO is not quite firmly attached. This method was selected as the most appropriate because of both the low-cost and the easy implementation.

The test description:

- the negative pressure was set on the ejector on the level of -10 kPA
- the ejector was activated
- the suction cups were put on the MO by which the MO was gripped
- the load was increased (by use of the PET bottles filled with water) up to the state of the MO release or the loose of firm grip of the MO
- by the above described method the effector was tested at the each level of the vacuum, starting at -10 kPa and finishing at its maximum (at approximately -90 kPa)
- the test was conducted at vertical and horizontal position of the MO
- during the test it was necessary to keep the MO dry and free of any dirt

4.3 The test results

As it is shown at the fig. 4, the load is given straight on the MO at the horizontal grip of the MO and at the vertical grip of MO the load is conducted by the PET bottles hanged on the lines. The test at each level of vacuum was terminated when the first deformation of suction cups had been visible. It is also evident from the results, that the load capacity is directly proportional to the level of the negative pressure. A slight deviation from a linear graph is caused by increase of the load always by one kilogram.

Fig. 4. The demonstration of tests at the horizontal and vertical load.

Tab. 5. The table of effector´s load capacity with the MO in the horizontal position.

Horizontal load		**Negative pressure [kPa]**								
		-10	-20	-30	-40	-50	-60	-70	-80	-90
Static load capacity [N]	9.81	x	x	x	x	x	x	x	x	x
	19.62		x	x	x	x	x	x	x	x
	29.43		x	x	x	x	x	x	x	x
	39.24			x	x	x	x	x	x	x
	49.05			x	x	x	x	x	x	x
	58.86				x	x	x	x	x	x
	68.67					x	x	x	x	x
	78.48						x	x	x	x
	88.29						x	x	x	x
	98.1							x	x	x
	107.91							x	x	x
	117.72								x	x
	127.53									x

x – the symbol for the firm grip

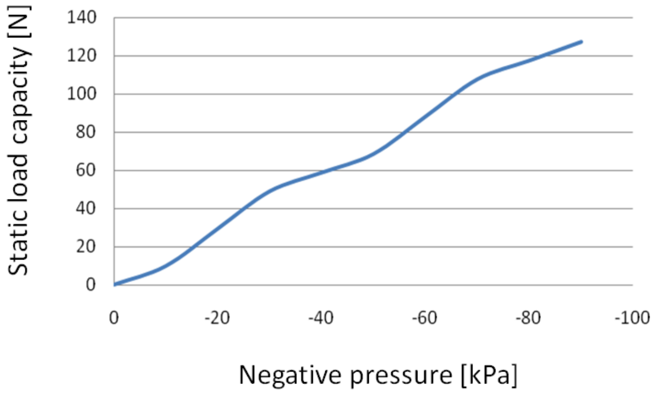

Fig. 5. The chart of static load capacity.
depending on the negative pressure at the horizontal grip of the MO

Tab. 6. The table of effector´s load capacity with the MO in the vertical position.

Vertical load		**Negative pressure [kPa]**								
		-10	-20	-30	-40	-50	-60	-70	-80	-90
Static load capacity [N]	9.81	x	x	x	x	x	x	x	x	x
	19.62		x	x	x	x	x	x	x	x
	29.43			x	x	x	x	x	x	x
	39.24			x	x	x	x	x	x	x
	49.05			x	x	x	x	x	x	x
	58.86				x	x	x	x	x	x
	68.67					x	x	x	x	x
	78.48						x	x	x	x
	88.29							x	x	x
	98.1								x	x
	107.91									x

x – the symbol for the firm grip

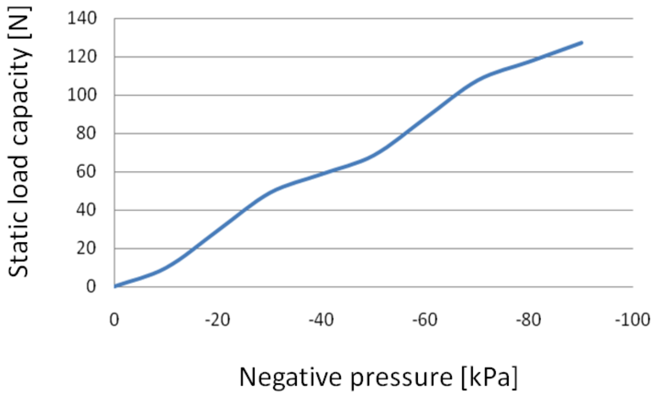

Fig. 6. The chart of the static load capacity.
depending on the negative pressure at vertical grip of the MO

According to the above texts it is apparent, that the effector´s load capacity is lower at vertical grip of the MO (also according to the manufacturer) than at horizontal grip. Therefore we will be further analyzing only the test results at the vertical grip of the MO.

Since it was calculated with the level of negative pressure at -70 kPa in the proposal it is the load capacity at this level decisive. The static load capacity at this level of pressure is 88.29 N. As the minimal grip force of the suction cups, viz. the formula (4), is 39.46 N the corresponding safety coefficient for the plexiglass with the minimal friction coefficient (0.55) is 2.23. Because of the possibility of effector use for manipulation with objects made from other materials for which we do not know the friction coefficient precisely it is necessary to conduct the tests again prior to every use of the new material of the MO in order to determine the safety of the operation.

5 CONCLUSIONS

The model of the vacuum effector had been designed according to which the vacuum effector has been implemented. Later on this effector has been tested. The test has shown that the designed effector meets all requirements, established at the beginnings of the design process, for use with the MO made from the plexiglass. It is necessary to perform these tests again for the MOs made from other materials because of the unknowingness of the exact friction coefficient of both the current and new MO with the suction cups.

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REFERENCES

[1] TOMÁŠ, Jaroslav. *Realizace efektoru s přísavkami pro PR ABB IRB 140*. Ostrava, 2010. Diplomová práce. VŠB - Technická univerzita Ostrava, Fakulta strojní, Katedra Robototechniky. Vedoucí práce Ing. Václav Krys.

[2] SKAŘUPA, Jiří. *Průmyslové roboty a manipulátory*. 1 vyd. Ostrava: VŠB – TU Ostrava, 2007. 260s. ISBN 978-80-2481522-0.

[3] MOSTÝN, Vladimír. *Modelování a analýza konstrukcí robotů II*. 1 vyd. Ostrava: VŠB – TU Ostrava, 2002. 111. ISBN 80-248-0022-5.

[4] PALKO, A., SMRČEK, J. *Robotika – Koncové efektory pre priemyslné a servisné roboty.* 1. vyd. Košice: SF TU Košice, 2004. 274. ISBN 80-8073-218-3.